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# TOBE: Tangible Out-of-Body Experience

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## ABSTRACT

We propose a toolkit for creating Tangible Out-of-Body Experiences: exposing the inner states of users using physiological signals such as heart rate or brain activity. Tobe can take the form of a tangible avatar displaying live physiological readings to reflect on ourselves and others. Such a toolkit could be used by researchers and designers to create a multitude of potential tangible applications, including (but not limited to) educational tools about Science Technologies Engineering and Mathematics (STEM) and cognitive science, medical applications or entertainment and social experiences with one or several users or Tobes involved. Through a co-design approach, we investigated how everyday people picture their physiology and we validated the acceptability of Tobe in a scientific museum. We also give a practical example where two users relax together, with insights on how Tobe helped them to synchronize their signals and share a moment.

## Author Keywords

Physiological Computing; Tangible Interaction; Spatial Augmented Reality; EEG; ECG; EDA

## ACM Classification Keywords

H.5.1 Multimedia Information Systems: Artificial, augmented, and virtual realities; H.5.2 User Interfaces: Prototyping

## INTRODUCTION

Wearable computational devices are more accessible and more popular than ever. These devices are personal and are embedded with physiological sensors, i.e. sensors that can monitor signals such as heart beats. Nowadays even brain activity is within reach of consumers thanks to cheap alternatives to medical equipment, such as the Emotiv Epoc<sup>1</sup> or, closer to the Do-It-Yourself community, the OpenBCI board<sup>2</sup>. Physiological computing is becoming mainstream. However, for the general public, the use of such sensors seems mostly centered around performance. Despite an era of personal development,

\*Co-first authorship, both authors contributed equally to this work.

<sup>1</sup><https://emotiv.com/>

<sup>2</sup><http://www.openbci.com/>

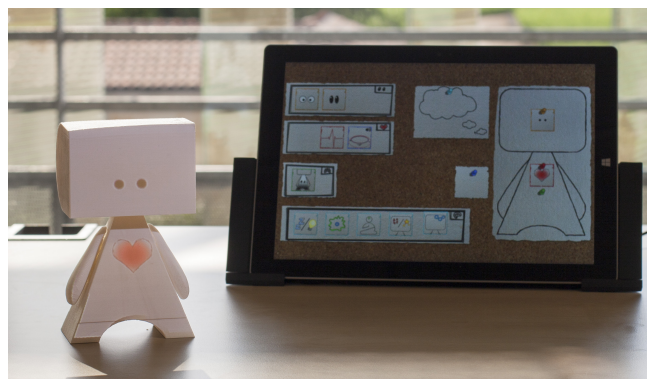


Figure 1: Tobe, the tangible avatar displaying real-time physiological readings along with the interface to control the different visualizations.

well-being and communication, how many smart watches and heart rate belts advertise themselves as sportspersons' best buddies, while they can account for so much more than *physical* health? Indeed, physiological computing is mature enough to assess mental states [4, 20, 30, 6]. Therefore, it could be used as a mean to better know our own self and others.

On the one hand, physiological technologies are not exploited to their full potential, on the other hand, we have end users that ignore what technology has to offer for their well-being. Some companies are pioneers, as for example Empatica and its Embrace smart watch<sup>3</sup>, but they focus on health applications and, consequently, the targeted consumers are still a niche. Both a process that will raise public awareness and a collection of meaningful use cases are missing. Finally, when bodily activity and mental states are at stake – which are difficult to conceptualize and often difficult to perceive – the feedback given to users matters for them to comprehend at first sight what is being measured. How to represent the arousal state of someone? How would *you* represent cognitive workload? We found little examples besides pies and charts, which are not always obvious informants in data visualizations – e.g. [13].

To address these issues, we first conducted surveys and interviews to gain insight about physiological feedback. We then created Tobe, a Tangible Out-of-Body Experience shaped as a tangible avatar (Figure 1). This avatar lets users freely explore and represent their physiological signals, displayed on the avatar itself using spatial augmented reality. The overarching goal is to help one reflect on her physiological and mental states in *her* own way. The main activity would be for users to

<sup>3</sup><https://www.empatica.com/>

actively *build* from the ground up their own self-representation and then visualize physiological signals through it. As such, we designed a modular toolkit around Tobe that can be used to customize any part of the system. Tobe has been tested on two different occasions in a scientific museum to collect user feedback. A specialized version of the system was also built to give biofeedback to multiple users in a relaxation task. Beside these two implementations, we identified potential future uses of the system, such as a biofeedback device for stroke rehabilitation or replaying inner states synchronized along with videos of cherished memories. The latter example could help create more cherishable versions of personal digital data [7].

Previous works do not embrace such system as a whole and are limited either to low-level signals or to emotions. Wearables were used in [29] to mediate affect using multimodal stimuli (sounds, heat, vibration, ...). However, as with the “Social Skin” project [27] – that also embodies emotions into actuated wearables –, the information given to those around was rather implicit. When a more comprehensible feedback was studied, as in [18], it was limited to anatomical models, for instance to teach children how the body works. Tobe, on the other hand, gives both access to meaningful visualizations and to additional cognitive states. Tangible proxies and material representations were already studied in [10], although the feedback was not dynamic and, once again, constrained to bodily activity. While we previously used a tangible puppet as a proxy for brain activity [5], the settings concerned scientific outreach and the feedback focused only on preprocessed brain signals, not on higher level mental states. Our toolkit pushes further the boundaries of the applications by giving access to physiological signals, high-level mental states as well as dynamic and customizable feedback.

Our contribution for this paper consists of a toolkit enabling users to create an animated tangible representation of their inner states. The toolkit encompasses the whole workflow, including the physical avatar creation, sensors, signal processing, feedback and augmentation. It was tested through two use cases, in public settings and with a multiple users scenario.

## REPRESENTING PHYSIOLOGICAL SIGNALS

Exposing physiological signals in a way that makes sense for the user is not trivial. Some types of signals might be more obvious to represent than others. For example, heart activity could be understood using a symbolic heart shape due to largely accepted cultural references. This question is, however, harder when talking about more abstract mental states such as workload. Nevertheless, even the dynamic representation of low-level physiological signals is still an open question at the moment [3]. We conducted two surveys to gain more insight about the knowledge and representations people had of different types of signals and high-level mental states.

In the first survey, conducted online, we asked 36 persons about their knowledge of physiological signals in general. We inquired about the self-awareness of inner states on a 7-points Likert scale (1: no awareness, 7: perfectly aware). About “internal physiological activities”, the average score was 3.5 (SD=1.4) and for “mental states”, the average score was 4.9

(SD=1.3). The latter score indicates that the participants were confident about their inner states, even though a whole literature demonstrates how difficult this is [17]. Interestingly, we also observed that most of the participants reduced mental states and physiology to emotions only. Mentions of any cognitive processes such as vigilance and workload were very rare (7 out of 36). This lack of knowledge about the inner self and the different cognitive processes is an opportunity to raise awareness of the general public about the complexity of the mind. When inquired about possible uses of a Tobe system, few respondents (6 out of 36) gave examples other than sports or health. This emphasizes the fact that the general public is unaware of possibilities of technology for well-being.

The second survey specifically investigated how users would shape the feedback. We focused on visual cues because it was easier to express on paper, but note that other modalities could be explored, such as sound [15]. We asked 15 participants to express with drawings and text how they would represent various metrics (Figure 2). There was little resemblance between subjects for a given high-level metric and even low-level ones – breathing and heart activity – sprang different views. For example, some people drew a physiologically accurate heart instead of a simple sketch. Overall, there was a wide variety of sketches and people were very creative. This highlighted the absence of consensus on how we conceive and view our inner states. Therefore, people could benefit from being able to tailor a meaningful and personal feedback.

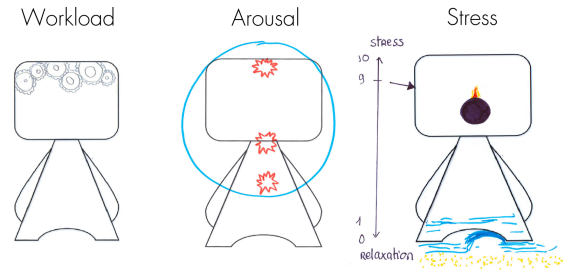


Figure 2: Sample of the drawings made by participants to represent various high-level metrics.

## TOOLKIT

We created a tangible anthropomorphic avatar, named Tobe as a host for displaying real-time feedback. We chose this form factor because we found evidence in the literature that this combination of anthropomorphism and tangibility can foster social presence and likability [25, 9]. This also reminds users and observers that the feedback is linked to an actual being; it helps to recognize Tobe as a persona and to bond with it, hence it facilitates engagement.

Our implementation uses open or low-cost hardware and we are releasing as open-source software the entire pipeline<sup>4</sup>, thus facilitating reproduction and dissemination.

## General Approach

We conceived a toolkit to assist the creation of representations of inner activities – our body at large and the hidden processes

<sup>4</sup><https://github.com/potioc/tobe>

of our mind in particular, making it visible to oneself and to others. The different components are highlighted in Figure 3. The first step consists in choosing a *metric*, e.g. the arousal level. For this given metric there are different ways to measure it, that include a combination of one or multiple *sensor(s)* and *signal processing* algorithm(s). One chooses a support to express this metric (e.g. tangible avatar, screen, speaker for sound) and creates a shape associated to it (e.g. a circle with a changing color, a rhythmic tone). The conjunction of both the shape and the support produces the *feedback*. It is an iterative process because when one acknowledges the feedback, it changes one's self-representation. Moreover, it creates a feedback loop which affects one's biosignals.

In order to help users mold the system to their likening, we identified three different degrees of freedom:

- The measured physiological signal or mental state (Metric)
- The form factor (Support)
- The display of the signals (Shape)

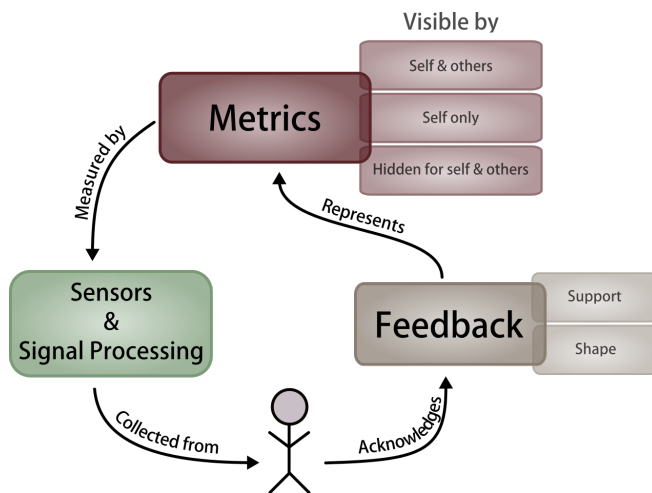


Figure 3: Simplified view of the toolkit that supports Tobe.

### Metrics

There is a continuum in the visibility of the signals and mental states measured from physiological sensors, i.e. metrics. We categorized those metrics in three different levels, depending on who can perceive them without technological help.

1. Perceived by self and others, e.g. eye blinks. Even if those signals may sometimes appear redundant as one may directly look at the person in order to see them, they are crucial in associating a feedback to a user.
2. Perceived only by self, e.g. heart rate or breathing. Mirroring these signals provides presence towards the feedback.
3. Hidden to both self and others, e.g. mental states such as cognitive workload. This type of metrics holds the most promising applications since they are mostly unexplored.

Lower levels (1 & 2) help to breath life into a proxy used to mediate the inner state of the user. These metrics are accessible to our conscious selves. On the other hand, level 3 metrics are little known and are hard to conceptualize for the general

public [17] and would benefit the most of a system enabling their visualization.

### Sensors and Signal Processing

Metrics were acquired from five physiological signals. We measured thoracic circumference for breathing, electrocardiography (ECG) for heart rate, electrodermal activity (EDA, i.e. perspiration) for arousal, electrooculography (EOG, eyes activity) for eye blinks, and electroencephalography (EEG, brain activity) for most high-level mental states – i.e. vigilance, workload, meditation and valence.

We created the sensors with a wearable form factor in mind. Since we used Tobe in public settings, it was important that the sensors were non-invasive (no need to remove clothes or apply gel to the skin) and be quick to install and remove, while being able to acquire a reliable signal. With the setup described in this section, we were able to equip the users and record physiological signals in less than two minutes.

The different sensors were embedded inside a lab coat (Figure 6) which could be put on quickly over daily clothes. This form factor provides enough room in the sleeves and the pockets to take care of the wiring and electronic components storage. The recording of the low-level physiological signals (i.e. everything except EEG) is done using the BITalino board, an Arduino-based recording device. It contains modules that amplify various physiological signals and it embeds a Bluetooth adapter as well as a battery to work in ambulatory settings. Each physiological signal or mental state index was sent to the other stage of the toolkit using LSL<sup>5</sup>, a network protocol dedicated to physiological recordings.

### ECG

We chose to use ECG for heart rate activity as it is more accurate than light emission-based methods to detect individual heartbeats [11]. Existing solutions for ECG require electrodes to be put directly on the chest, e.g. heart rate monitor belts. We instead opted for installing TDE-201 Ag-AgCl electrodes from Florida Research Instruments on both wrists of the user (ECG needs two electrodes diametrically opposed to sense heart electrical activity). The electrodes were attached to an elastic band sewn inside the end of the lab coat sleeves which could be tightened with velcro straps (Figure 4a). ECG was recorded with the dedicated ECG module of the BITalino.

### EDA

We measured arousal – which relates to the intensity of an emotion and varies from calm to excited (e.g. *satisfied* vs *happy*) – using EDA. When measuring EDA, most accurate readings can be obtained from the tip of the fingers. However, since it is difficult to manipulate a tangible interface and controls while having hardware attached to one's fingers, we acquire the signal from the palm of a single hand instead. We assess skin conductance from two small conductive thread patches sewn inside a fingerless glove (Figure 4b). Because the BITalino EDA amplifier was not sensitive enough for signals acquired from the palm we made our own, replicating the schematics described in [21].

<sup>5</sup><https://github.com/sccn/labstreaminglayer/>





Figure 4: Wearables. *a*: coat embedding ECG sensors; *b*: fingerless glove measuring EDA; *c*: breathing belt; *d*: EEG headband.

### Breathing

For breathing, we built a belt based on a stretch sensor (Figure 4c). A conductive rubber band was mounted as a voltage divider and connected to an instrumentation amplifier (Texas Instruments INA128). As opposed to piezoelectric components, that are sensitive to momentous speed instead of position, stretch sensors can directly map users' chest inflation onto their avatar.

### EEG and Eye Blinks (EOG)

We built our own EEG helmet based on the open hardware OpenBCI board (Figure 4d). To shorten setup time we used dry electrodes – the same TDE-201 as for ECG for the forehead, and elsewhere TDE-200 electrodes, which possess small protuberance that could go through the hair. Using a stretchable headband, we restrained electrodes' locations to the rim of the scalp to avoid difficulties with long-haired people. In the 10-20 system, electrodes were positioned at O1, P7, F7, FP1, F8, T8, P8 and O2 locations – reference at T7, ground at FP2. We used OpenViBE to analyze physiological data in real time<sup>6</sup>. EEG signals were re-referenced using a common average reference. Specific frequencies (see below) were extracted with a band-pass filter, taking the log of the power of signals in order to normalize indices. Eye blinks were detected when the signal, after DC drift removal, exceeded 4 times the variance in the F8 electrode. We used the following metrics:

- **Vigilance:** appoints for the ability to maintain attention over time. We use the ratio between beta frequency band (15-20Hz) and theta + low alpha frequency band (4-10Hz) for all electrodes [19].
- **Workload:** increases with the amount of mental effort required to complete a task. We use the ratio between delta + theta band (1-8Hz) in near frontal cortex (F7, FP1, F8, T8) and wide alpha band (8-14Hz) in parietal + occipital cortex (P8, P7, O2, O1) [1, 26].
- **Meditation:** we used instantaneous phase locking value between front (FP1, F7, F8) and rear (O1, P7, P8) parts of the brain in alpha + beta bands (7-28Hz) [5] – mindfulness and body focus practices decrease the synchronization while transcendental practice increases it.
- **Valence:** designates the hedonic tone of an emotion and varies from positive to negative (e.g. *frustrated* vs *pleasant*). We use the ratio between the EEG signal power in the left (F7, P7, O1) and right (F8, P8, O2) cortex in the alpha band (8-12Hz) [16].

In earlier iterations of the system we tested the use of an Emotive Epoc headset to account for brain activity. The Epoc is a consumers-oriented EEG device, easier to install than medical headsets that use gel. However, it still requires a saline solution that tends to dry over time, causing additional installation time between users. Moreover, good signal quality was next to impossible to obtain with long haired persons. Another downside of consumers-oriented EEG headsets is that they usually conceal signal processing behind proprietary algorithms, with little scientific evidence on what is truly measured. While building a tailored EEG helmet, we took the upper hand on the whole pipeline. With access to raw EEG signals, we looked into the literature to match the inner state we wanted to measure with actual neurological markers.

### Feedback

The feedback consists in both a support and a shape.

#### Support

3D printing a tangible avatar is a powerful incentive for customization. While the version of the system that we deployed in the scientific museum used an already modeled and 3D printed incarnation of Tobe because of time constraints, a user of the system could change the parametric model in order to obtain an avatar that pleases her. The process would be similar to how the appearance of a Nintendo “Mii” can be tuned, except for the tangibility. As a tradeoff between preparation time and customization, we prototyped a “Mr. Potato Head” version of Tobe, with parts ready to be assembled (Figure 5b).

#### Shape

The visualization of users' signals are displayed onto Tobe using Spatial Augmented Reality (SAR), as introduced by Raskar et al. [23]. SAR adds dynamic graphics to real-world surfaces using projected light. Despite external hardware – i.e. a projector and eventually a tracking device (Figure 6) – SAR is an easy solution to prototype a system, faster to deploy than putting actual screens in users' surroundings. The augmentation occurred within vvvv<sup>7</sup>, a software that uses real-time visual programming to render 3D scenes. We used a LG PF80G projector of resolution 1920x1080 and the tracking of Tobe was achieved with an OptiTrack V120:Trio, running a 120 FPS with an overall latency of 8.3ms and a precision of 0.8mm. The projector was calibrated with the OptiTrack using OpenCV's camera calibration function.

<sup>6</sup><http://openvibe.inria.fr/>

<sup>7</sup><http://vvvv.org/>

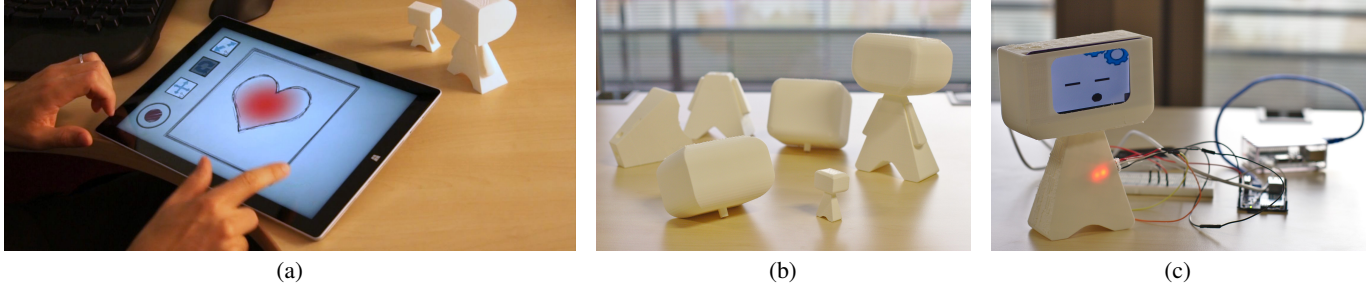


Figure 5: *a*: Simple multitouch animator allowing users to create and animate visual feedback. *b*: Customizing the tangible support of Tobe can be achieved using modular body pieces; *c*: it is also possible to embed electronics inside the support to have a standalone Tobe.

As an alternative to SAR, Tobe can be embedded with small screens, LEDs, actuators and small electronics components so that it represents a standalone unit. We already have a proof of concept of such an implementation thanks to the easiness and accessibility of the building blocks that go with the Arduino platform and the Raspberry Pi (Figure 5c).

#### Customization

We conceived a GUI that let users draw a picture and animate it according to their wishes. The animator is touch based; users press a “record” button and animate the picture with gestures (Figure 5a). Once done, the animation’s timeline is automatically mapped to the chosen signal. This animator is kept simple on purpose, it is designed for novice users and as such must remain easy to understand and operate for someone not familiar with animation. Only three basic operations are currently supported – scaling, rotation and translation – and yet it is sufficient to generate meaningful animations. For example, scaling makes a heart beat, translation moves a cloud along respiration and rotation spins cogs faster as workload increases. An advanced tool such as Photoshop has already been integrated as a proof of concept, but the simplicity of the current GUI does not impede users’ creativity and is already sufficient to enable a tailored feedback.

#### TOBE IN THE WILD

We used and tested Tobe in two different applications: as a demonstration in a scientific museum and as a multi-user biofeedback device for relaxation and empathy.

#### Tobe in a public exhibition

Using a co-design approach, we intervened in a scientific museum over two half days, proposing to passersby to try out Tobe. Around twelve persons tested the system. We built the sensors and prepared the signal processing beforehand because these steps require hardware and expertise. Five high-level metrics were selected: workload, vigilance, meditation, valence and arousal. These metrics were chosen because the general public showed interest in them (meditation and emotions) or because they could benefit from being better known (workload and vigilance). Due to the short duration of our exhibitions, we also set the corresponding feedback (both support and shape), according to the outcome of the questionnaires about people’s representations.

After we equipped participants, we gave them “activity cards”, a collection of scenarios designed to modify their inner state and to prompt self-investigation (Figure 6). In particular, these cards asked them to perform riddles and arithmetic problems involving working memory to increase their workload [6]; to look at cute and *less* cute images to change their valence and arousal levels (a typical emotion elicitation approach [16]), to perform a breathing exercise to help them meditate, and to play a “Where’s Waldo?” game to increase their vigilance [6]. These sole cards sufficed to engage participants for a few tens minutes without our intervention.

We created the activity cards after our first intervention in the museum. There were some candies left at disposal next to Tobe to lure museum’s visitors to our booth. At some point, one user wanted to see how different tastes affected the emotional valence that was displayed on Tobe. This proved to be a fun activity for him – and for the people around. Having such goal in mind was an effective way to drive participants.



Figure 6: In a scientific museum, various activities were proposed to visitors in order to prompt self-investigation. The setup consists of a projector handling the augmentation and an OptiTrack for the tracking.

One degree of freedom was left to users by the mean of a graphical interface (see Figure 1). They had to manipulate the GUI on a nearby tablet to drag and drop visualizations on predefined anchor points. Users could customize some of Tobe’s aspects (eyes and heart rate feedback) and among the 5 high-level metrics available, they selected which one to study at a particular time. When at first we tested Tobe with *no* degree of freedom – i.e. all metrics were displayed altogether – we realized that users were too passive and quickly overwhelmed. The GUI helped to focus and engage users.

To further engage users, Tobe was tracked and participants were asked to put Tobe on a spotlight to “awake” it – i.e. to start physiological signals’ streams. The action of bringing life to an inanimate puppet goes well with making the world “magical” again [24], that is to say to use the power of abstraction of modern computer science in order to bring back awe. The aim is not to take benefit of ignorance but to strengthen the amazement that technology can offer. We were ourselves pleasantly disturbed and surprised when we happened to hold in our hands a representation of our beating heart during some routine test. Suddenly the relationship with the digital content felt different, truly tangible.

### Tobe for multi-users relaxation

We tested Tobe as a relaxation device for two users (Figure 7). The objective was to see if Tobe could be used both as a biofeedback tool and for collaboration.

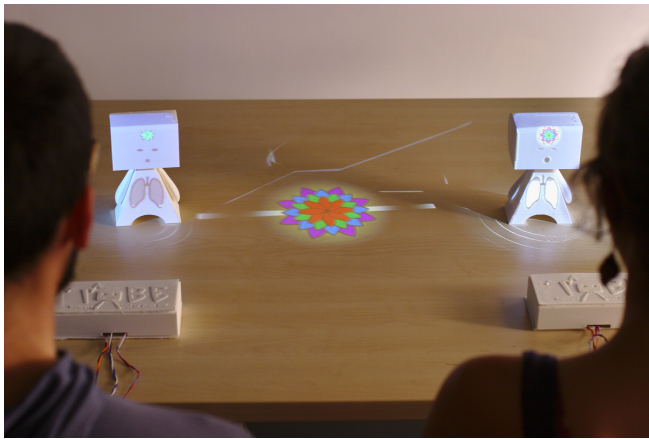


Figure 7: Multi-users application: relaxation through cardiac coherence.

### Implementation

This version of Tobe relies only on respiration and heart rate variability. It relates to cardiac coherence: when someone takes deep breaths, slowly ( $\approx 10$ s periods) and regularly, her or his heart rate (HR) varies accordingly and the resulting state has positive impact on well-being [14]. During cardiac coherence, HR increases slightly when one inhales and decreases as much when one exhales. We took the magnitude squared coherence between HR and breathing signals over 10s time windows as a “relaxation” index.

Sensors consisted in a breathing belt and in a pair of elastic bands around the wrists to measure ECG. We used OpenBCI instead of BITalino to measure ECG and breathing in order to get more accurate readings. Indeed, the OpenBCI amplifier has a resolution of 24 bits instead of 10 for the BITalino.

There were two Tobes on the table, one for each participant. They were not tracked. Breathing activity was pictured with inflating lungs onto the torso; cardiac coherence with a blooming flower onto the forehead. The synchronicity *between* subjects – users’ heart rates varying at the same pace – was represented with a similar but bigger flower projected between both Tobes. Additionally, “ripples” on the table, around Tobes’ feet, matched heart beats.

### Protocol

We asked 14 participants, by pairs, to come and use Tobe to reach cardiac coherence – 6 females, 8 males, mean age 25.3 (SD=2.8). Participants were coworkers from the same research institute and already knew each other. Participants were seated on each side of a screen and instructed not to talk to each other. We presented them the cardiac coherence activity as a relaxation exercise. Afterwards, we equipped them and turned the system on.

The experiment comprised of three sessions of 5 minutes. During the first session, participants had to individually learn how to reach cardiac coherence. A smaller screen on the table prevented them to see each other’s Tobe. They had to imitate the breathing pattern given by a gauge going up and down in 5s cycles onto Tobe’s body. The lights of the room were dimmed to facilitate a relaxation state and each participant was given headphones playing back rain sounds.

After the training session, the screen separating the two Tobes was removed. Participants were then instructed to repeat the same exercise as before, but without the help of the gauge. They could see their colleague’s Tobe. However, there was no interaction between them at this stage – it served as a transition between a self-centered task and a collaboration task.

During the third session, participants were instructed to synchronize their *hearts*. In order to do so, they had to both reach cardiac coherence while breathing on the same rhythm – with no other way to communicate than using their Tobes.

After this final session, we gave questionnaires to participants and conducted informal interviews with them to gather feedback about their experience.

### Results

From the questionnaires, that took the form of 5-points Likert scales, participants reported that they were more relaxed after the end of the session: 4.36 on a scale ranging from 1 “much less relaxed” to 5 “much more relaxed” (SD=0.74). Beside the fact that Tobe acted as an effective biofeedback device, the experiment was also a chance to introduce participants to activities centered around well-being, as few of them were practicing relaxation or meditation in their daily life – 1.93 score (SD=1.44) with 1 “never” and 5 “regularly”.

During the interviews, the participants reported that they appreciated the feedback, saying that it formed a coherent experience – e.g. ripples on the table and sounds of rain. Among the few that were practicing yoga regularly, one praised how Tobe favors learning-by-doing over wordy and disrupting instructions but had troubles to follow the 10s breathing cycle since it differed from his usual practice. We had mixed reviews about the visualization associated to breathing, mostly due to the mapping between Tobe’s lungs and the measured thoracic circumference being dynamically adapted over time rather than calibrated per user with a min/max. Because of that, some users had to draw their attention away from the breathing patterns in order to achieve cardiac coherence. These two last issues could be resolved by giving users access to the signal processing through our toolkit.



We received comments about how a qualitative and ambient feedback (blooming flower) fostered a better focus on the activity compared to the use of quantitative metrics which are an incentive for competition. Indeed, apart from some comparisons made during the second session, participants did use their Tobes for collaboration. Users described how they use the respiration of their partner to get in sync during the third stage – usually by waiting before inhaling. One participant described how she tried to “help” her companion when he struggled to follow. Another retold how she quickly resumed her regular breathing when she saw that a brief hold troubled her colleague. More playful, a participant laughed afterward at how he purposely “tricked” twice his partner. Even with a communication channel as basic as the display of thoracic circumference, rich interactions emerged between participants over a short period – 5 minutes that felt like less for many of them.

Overall these findings suggest that Tobe could be employed as a proxy for interpersonal communications and that it has an interesting potential for enhancing well-being.

## DISCUSSION AND POTENTIAL APPLICATIONS

The toolkit that we propose uses physiological sensors to let people grasp and share their inner states. Even if the modules we chose promote the inclusion of novices – e.g. visual programming that could be easily extended in OpenViBE or vvvv, they can be switched to other components that would suit more experienced users – e.g. Matlab for signal processing. Moreover, we explored multiple ways to support the feedback via SAR and embedded electronics. We think that SAR provides a very flexible and high-resolution option for prototyping different feedbacks. However, for long term usages and deployment, we would recommend the use of more embedded solutions since SAR still suffers from a more complicated installation and occlusion issues.

Beside the applications that we tested in the wild, we drew usages for Tobe by exploring different design dimensions. We considered on the one hand the number of users, Tobes and external observers involved, and, on the other hand the time and space separating the feedback and the recordings. The following scenarios could be used by researchers and enthusiasts to explore the possibilities offered by our toolkit.

### *One User*

Tobe can be used as a biofeedback device with a specific goal – e.g. reduce stress – or to gain knowledge about one self. A feedback about workload and vigilance would prevent overwork. Insights gathered from an introspection session with Tobe could also be employed to *act* better. For example, it might be useful to realize that you are irritated before answering harshly to beloved ones.

### *One User and Observer(s)*

Tobe could be used in a medical context. Indeed, in stroke rehabilitation, patients with motor disabilities may regain mobility after long and difficult sessions of reeducation. However, occasional drawbacks may create anxiety and a counterproductive attitude towards therapy, which leads to even more anxiety. A Tobe could help patients and therapists acknowledge this

affective state and break this vicious circle. Autistic persons could also benefit from using Tobe since it is difficult for them and their relatives to gauge their inner state. Explicit arousal could help their integration into society. An offline experiment – i.e. after signals were recorded – pointed to this direction [8].

### *Multiple Users and Tobes*

Using Tobe as an alternate communication channel during casual interactions would help to explore connections with relatives, discover and learn from strangers or improve collaboration and efficiency with coworkers. This has been partially explored through the “Reflect Table”, which gives a feedback about the affective state of meeting participants [2]; and a bicycle helmet that displays the heart rate of the wearer to the other cyclists nearby has been proposed to support social interactions during physical efforts [28].

### *Archetype of a Group*

Tobe could summarize the state of a group. A real-time feedback from the audience would be a valuable tool for every speaker or performer. To pace a course, a teacher could use one Tobe as an overall index that aggregates the attention level of every student in the classroom. Through behavioral measures and with a feedback given afterward, this was investigated in [22].

### *Time and Space*

One could want to analyze or to recall inner states after an event. Tobe could replay how one actually felt alongside a video of a cherished moment. If it is not time but space that separates a Tobe from its owner, imagine a distant relationship where the Tobe on your desk slowly awakens as the sun rises in the timezone of your beloved one – and you would wait for Tobe’s vigilance to increase to a sufficient level before you pick up your phone for a chat, knowing that your soul mate is a bit grumpy at the beginning of the day. Besides this theoretical view, it has been hinted that even low-level physiological signals could enhance telepresence [12].

## CONCLUSION

We have presented an open system aimed at externalizing physiological signals and mental states in order to offer users a shared “out-of-body experience”. This system covers the entire pipeline, from signals’ acquisition to their visualization. The open nature of the toolkit may be used to introduce STEM disciplines (Science, Technologies, Engineering and Mathematics) to the general public through inquiry-based learning, while end usages can steer them to cognitive science, psychology and humanities. Future work will include testing Tobe in classrooms or public workshops where users will be invited to build their own self-representation from the ground up, including the tangible support, sensors and the feedback design. Longer usages of the toolkit, over multiple days or weeks, will also be the opportunity to strengthen signal processing in order to provide more reliable mental states that could be displayed between users. Tobe could be used to ease social interaction or to foster empathy towards others. Giving users the tools to investigate their own bodies and mind is a good way to empower them and prompt self-reflection.



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